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Final Report

on

PROPAGATION CHARACTERISTICS OF LASER SUPPORTED COMBUSTION WAVES IN FLOWING MEDIA

AFOSR-81-0083

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Research Objectives

The basic research objectives for the present research program are itemized below.

1. Perform stability analyses of LSC waves in which molecular absorption is the primary absorption mechanism. Such analyses will consider one-dimensional flows in varying area passages and attempts will be made to find geometries and heating conditions which enhance stability. Similar analyses will also be conducted for inverse bremsstrahlung absorbers in which molecular seedants such as H_2O or Cs are present.
2. Investigate the feasibility of using circumferentially uniform radiation to sustain an LSC wave. This analysis will include a formulation of the stability problem for this two-dimensional heating mode, and an assessment of the advantages and disadvantages of this approach as compared to the more standard approach in which the energy beam and the flow are co-axial.
3. Look for absorptivity characteristics and energy deposition patterns which will yield improved wall cooling characteristics, increased radiation trapping and resultant reductions in energy losses, reduced frozen flow losses, and improved stability characteristics.
4. Identify important parameters in ignition transients and assess this effect on a propulsive system, and
5. Assess the general effects of variations in the wavelength of laser radiation (from 10.6μ) on the above and related parameters. This assessment should take into account those wavelengths for which new laser systems are being developed and the advantages of these various laser systems.

Status of Research Effort

As an initial step in understanding the behavior of laser supported plasmas in pure hydrogen, a computer code has been written to determine the high temperature properties of equilibrium hydrogen. Specific properties which are computed include the absorptivity, equilibrium concentrations, enthalpy, internal energy, viscosity and thermal conductivity. The results have been verified against existing data in the literature. Capabilities for routine calculation of the properties of high temperature hydrogen are necessary for addressing questions such as the radiative losses from the plasma, and the preferred laser wavelength.

Some one-dimensional laser supported plasma calculations are being performed using these property variations. Calculations such as these are useful in the magnitude of the absorptivity change, and the appropriate temperature range which is necessary to ensure stable a low-temperature plasma which is effective for propulsion. These calculations are being attempted with an unsteady time-marching procedure which should yield results for the final steady state as well as for the stability of this condition. The flow configuration being studied includes a choked throat downstream of the absorption region which controls the flow in a manner analogous to what occurs in experimental situations. Preliminary results indicate that in the presence of a choked throat, the propagation speed of the plasma actually decreases as the laser intensity increases.

A review of propulsive devices using microwave energy and solar energy is also under way. Recent papers have proposed using microwaves to dissociate hydrogen to its elemental state. These hydrogen atoms are then allowed to recombine and propulsion is obtained via a "free-radical" process. Detailed review of this process reveals that this procedure is not a free-radical process, but is directly analogous to laser propulsion. The microwave

energy is coupled to a flowing gas through an absorption mechanism, and it is the microwave energy (not the recombination energy) which is available for propulsion. The details of the absorption process are much different because of the significant change in wavelength, and a comparison of these processes is useful as an aid in understanding laser absorption.

A review of the possibilities of direct solar absorption is also under way. The maximum temperature to which a gas can be heated with solar energy is limited (by second law considerations) to the effective surface temperature of the sun. This temperature, approximately 6000K, is too low to enable continuum absorption process to be realized in hydrogen, however, there are possibilities for obtaining good broad-band absorption in other gases.

Finally, a review of useful beamed energy experiments is under way. An experiment to measure thrust and specific impulse from a small CW engine appears to be an important advance. No such measurements have been attempted yet, but they currently look feasible. Diagnostic measurements of the detailed characteristics of a plasma in flowing stream of hydrogen also are highly important. Measurements of the temperature profiles inside the plasma including heavy particle and electron temperatures are invaluable in furthering our understanding of this process. Diagnostic information would also enable improved analytical models to be developed. Improved analyses are critically needed for guiding and interpreting experiments. Other experiments of importance include measurements at shorter wavelengths (than 10.6μm) and investigations of the effects of simultaneously absorbing two beams of widely disparate wavelengths.

Professional Personnel Associated with Research Effort

Professional Staff

Charles L. Merkle, Principal Investigator, Professor, Mechanical Engineering

Graduate Students

Michael J. Stanek, Graduate Assistant, February 1981-present. Anticipated M.S. thesis title, "Analytical Studies of the Absorption Mechanisms of Equilibrium Hydrogen."

Anil Gulati, Graduate Assistant, September 1981-present.

Interactions (Spoken Papers)

"Analysis of Laser Supported Combustion Waves in Flowing Media," Rocket Propulsion Research Symposium, Lancaster, CA, March 26, 1981.